Variation in Latitude of the Greater Sun-spot Disturbances, 1881–1903. By the Rev. A. L. Cortie, S.J.

A former paper (*Monthly Notices R.A.S.*, lx. No. 8) contains a list of 115 greater sun-spot disturbances drawn at Stonyhurst during the years 1881–1899, as also a brief description of the life-histories of the same groups, covering a period of 255 solar rotations. In general, by a greater disturbance is meant either a single spot or group of spots, the area of which amounted to $\frac{1}{1000}$ of the Sun's visible disc, returns of the same spot or group being reckoned as a single disturbance. A few of the groups admitted into the list, although not attaining the disc-area required, were either recurrences, as distinguished from returns, of these groups, or in some special way connected with them. To make the record complete to the end of the year 1903, eight other groups have been added to the list, two from the Greenwich volumes for the years 1900 and 1901, and six more for 1902 and 1903, of which the heliographic latitudes have been very kindly furnished me by Mr. Maunder.* The total number of disturbances therefore discussed is 123 for the period of twenty-three years during which solar observations have been continuously made at Stonyhurst.

In view of recent criticisms on the absolute validity of Spörer's law regarding the variation of the zones of sun-spot activity with the progress of the sun-spot cycle, a chart (Plate 17) has been prepared to accompany this paper, on which the mean heliographic latitudes of the greater and associated disturbances have been plotted for each year as a series of points, with a number attached to each referring to the list of these disturbances before published (*loc. cit.* pp. 532–535). For such disturbances may legitimately be regarded as indices of the chief foci of solar activity, and any progressive shiftings in the zones of sun-spots, if it exists, should be chiefly reflected in them. That the inclusion of smaller disturbances on the chart would not materially alter the zones of sun-spot activity has been ascertained by a comparison with the diagram containing the mean daily area of sun-spots for each degree of solar latitude for the period 1874–1902 as measured on the Greenwich photographs, and published with accompanying tables (*Monthly Notices R.A.S.*, lxiii. No. 8).

Spörer's law of sun-spot variation in latitude contains two main propositions, the one, that the mean latitude of sun-spots diminishes gradually from $\pm 30°$ at times of solar maximum to $\pm 5°$ at times of minimum; the other, that before a sun-spot cycle is completed a second begins abruptly by the appearance of sun-spots in high latitudes. His words are : " A partir du mini-

* These eight disturbances are numbered 123–130 on the chart, the Greenwich group numbers being 4915, 4953, 4968, 4990, 5093, 5098, 5100, 5104.

mum, les taches, qui avaient depuis longtemps déserté les hautes latitudes, s'y montrent brusquement vers $\pm 30°$" (*Comptes Rendus*, cviii. 486). The process, therefore, is that of a succession of overlapping waves of activity descending from higher to lower latitudes. All solar observers will be agreed as to the general correctness of the first proposition. An inspection of Spörer's own charts, published in the Potsdam Observatory volumes, is sufficiently convincing on this point. At the same time all will equally admit that a mean latitude curve of sun-spots drawn for each solar hemisphere north and south of the equator is not a continuous curve, but that while on the whole the decline in latitude is gradual and continual, it proceeds in a series of waves. This is well shown in the curve drawn by Father Braun from observations taken at Kalócsa during the period 1880–1884, and reproduced in Dr. Lockyer's paper on this subject (*Proc. R.S.*, vol. lxxiii., and *Monthly Notices*, Appendix to vol. lxxiii.). In this paper, however, Dr. Lockyer comes to the conclusion that Spörer's law gives only a very general idea of sun-spot circulation, and that the curves are but the integrated result of a series of well-defined spot-tracks which are analogous to atmospheric storm-tracks on our globe. These "spot-activity tracks," according to Dr. Lockyer, commence successively in higher latitudes as the maximum is approached, and then fall nearly continuously in latitude. Instead, therefore, of two large overlapping waves, the action would be a succession of smaller waves or tracks; and whereas, according to Spörer, a large mean latitude wave falls continuously from higher latitudes at maximum to low latitudes at minimum, the starting points of Dr. Lockyer's tracks increase in latitude as maximum is approached. Still they all tend downwards, their deviations being from higher to lower latitudes. But it would appear from a study of the mean heliographic latitudes of the greater disturbances for the period under discussion, that the wave of sun-spot activity is highest at maximum, descends as minimum is approached, and after minimum that the direction is polewards until a second maximum is attained. This hypothesis would substitute for Spörer's large overlapping high to low latitude waves and Dr. Lockyer's series of "spot-activity tracks" a wave which falls from maximum to minimum and then rises. In so far as Dr. Lockyer places the successive waves with their starting points in higher and higher latitudes as maximum is approached, this suggested wave of "limiting sun-spot latitude" would pass through his successive points, but would disagree in making the trend of activity polewards from minimum to maximum, instead of towards the equator. It would contravene, too, the second main proposition of Spörer's law. But it would bring the variation of latitude in the case of greater spot disturbances into accord with the general poleward tendencies of the centres of prominence action from minimum to maximum, and the gradual opening out of the great coronal streamers as maximum is approached. At times of

solar maximum, as for example in 1893, nearly every latitude of the solar surface is disturbed with spots, extending from $-6°$ to $-30°$ in the example quoted. This general disturbance affects the prominences and corona and all other phenomena indicative of solar activity. Hence it is that prominences are found in the polar regions at such seasons of solar unrest, and that the coronal streamers are so widely diffused round the solar disc. At such times magnetic storms are more frequent and violent upon the Earth, pointing to a connection with the generally disturbed state of the Sun, rather than with isolated phenomena as spots, or faculæ, or polar prominences, all attempts to connect magnetic storms with such particular phenomena having so far proved unsuccessful (*cf.* "On the Connexion between Solar Spots and Earth-magnetic Storms," Sidgreaves, *Memoirs R.A.S.*, vol. liv. "Minimum Sun-spots and Terrestrial Magnetism," Cortie, *Astro-physical Journal*, vol. xvi. No. 4; and "Solar Prominences and Terrestrial Magnetism," Cortie, *ibid.* vol. xviii. No. 4). Nor is there any radical change in the constitution of the spots at various epochs of a sun-spot cycle, so far at least as can be gathered from my own observations of the red-end spectrum of sun-spots extending intermittently over a period of twenty years. But on this point my observations are contravened, at least in the earlier years, by the results from South Kensington obtained in the yellow-blue region of the spectrum. However, whether or not the character of the spots changes with the progress of the cycle from minimum to maximum, there seems to be sufficient evidence to show a distinct movement to higher latitudes when the spots become more frequent and larger.

From the chart it will be seen at once that during the period discussed the greater disturbances were much more frequent in the southern than in the northern hemisphere, though the law of variation in latitude is equally shown in both. Taking the southern hemisphere, spots of this class declined in latitude from $-29°$ in the maximum year 1882 to $-5°$ in 1887, but then began to go polewards again, No. 39 in the last quarter of 1888 being in latitude $-14°$, No. 42 in the middle months of 1889 being in latitude $-22°$, followed by No. 44 in latitude $-23°$ in the last three months of 1890, and culminating in No. 52 of 1892 June, about the time of maximum, in latitude $-31°$. Similarly, in the northern hemisphere, Nos. 43 and 45 of 1890 in latitudes $+21°$ and $+20°$ culminated in No. 49 of 1892 March in latitude $+28°$. In the next cycle the latitudes in the southern hemisphere descended from $-16°$ for No. 99 of 1896 November to $-8°$ for No. 106 of 1898 January and $-9°$ for No. 110 of 1899 March, and then began to rise, No. 113 in 1900 being at $-12°$, and Nos. 117, 118, and 120 of 1903 being between latitudes $-20°$ and $-24°$. A corresponding rise took place in the northern hemisphere from No. 109 of 1898 August in latitude $+14°$ to No. 115 of March 1902 in latitude $+25°$. It is to be noticed that, the foci of activity having reached $\pm 20°$ in the

years 1889–90, disturbances about the same latitude continued to occur until the end of 1895, though they ceased in the belt $-25°$–$30°$ for the southern hemisphere in 1894 May and for the northern hemisphere after 1892 March. Spörer has already indicated the mean latitudes $\pm 20°$ as the seats of great disturbances about the times of maximum. At the times of maximum too not only are greater disturbances found in high latitude zones, but in all zones. For instance, the belt at mean latitude $-8°$ S., which had shown many signs of activity during the minimum years 1887–1889, again became active in 1893 August, a maximum year, no fewer than six greater disturbances occurring in a belt between 1893 August and 1894 February. The same belt or zone was not again active until 1897–1899, after which the greater disturbances began to go polewards once more. Very remarkable too is the persistence of a region of disturbance between the limits $-20°$–$26°$ from 1891 September to 1893 March, the groups being numbered on the chart 47*a*, 47*b*, 47*c*, and 47*d*, their life-histories showing that they were all linked by means of smaller disturbances in the same region. The great magnetic storm of 1892 February was connected with this persistent activity, as indicated by the spot-groups. Two smoothed curves have been drawn on the chart to indicate the nature of the variation in latitude, as shown by the greater disturbances, and these have been called curves of "limiting latitude." The dotted portion of the curve for the northern hemisphere denotes a dearth of points to settle the trend of the curve for the period 1886–1890, though the fall from 1882 to 1886 and the rise subsequently to 1890 is very evident, and similarly for the southern hemisphere in 1900–2.

In Dr. Lockyer's paper (*loc. cit.*) the "spot-activity tracks" are formed by joining together successive centres of sun-spot activity, such as are tabulated and shown diagrammatically in the Greenwich results already referred to, the observations being grouped in strips of latitude 3° in width. Assuming a general trend of sun-spot activity towards the equator from the poles, such as is demanded by Carrington and Spörer, and given a number of centres of activity, it is evident that such tracks can be formed by joining together the different centres of activity. But the validity of this interpretation of the variation of the spots in latitude may be questioned when it is observed that various centres of activity that ascend from lower to higher latitudes, from minimum to maximum, are taken as the starting-points of tracks which are descending. Would it not be at least equally legitimate to make a series of ascending tracks at such epochs, which would be more consonant with the trend of the centres of prominence activity? Again, although there is distinct evidence of various latitude zones becoming intermittently active at different times in a spot cycle, and prescinding from the fact that in order to form "spot-activity tracks" it is necessary to join together spots that differ widely in longitude

and have only a fortuitous connection of latitude with one another, such tracks would have to include regions which are either disturbed for a long time or regions which are free from spots for a long time. For instance, the disturbances numbered 47*a*, 47*b*, 47*c*, 47*d* on the chart are all parts of one great disturbance which was located in that particular six degrees of latitude for 527 days. The disturbances in this position at least, which included some of the greatest of the last maximum, cannot be isolated the one from the other to form different points in various tracks. In Dr. Lockyer's diagram three tracks occur during this period.

In the paper (*Monthly Notices R.A.S.*, lxiii. No. 8) containing the Greenwich results it is noticed that "at minimum each hemisphere, considered separately, showed two clearly defined spot-zones marked off from each other by a broad belt in which there were no spots at all. This was especially marked in the years 1889 and 1890, when the very region, centering about latitude 15°, which when an entire solar cycle is considered is the most prolific of the whole solar surface, was completely free from spots." The same fact with regard to the greater disturbances is also shown on the chart, and the interpretation suggested is that the new cycle is beginning by the ascent of a series of disturbances to higher latitudes, which culminate at the maximum. Meanwhile the former cycle is dying out in low latitudes, and thus the central regions are left bare of spots. This dearth of spots in central regions is not so marked at the succeeding minimum. These facts, however, as to the persistence of disturbance in definite regions at some epochs and dearth of spots at others do not lend much countenance to the view of the variation in latitude being effected by a series of "spot-activity tracks." Is it not rather a matter of intermittent action in belts or zones? In this connection the series of disturbances in the latter half of 1893, numbered 66–71, which formed a belt in latitude −6° to −9° is noteworthy.

The following conclusions would seem to be warranted by the facts adduced :—

1. Greater disturbances are most prevalent in high latitudes at or near the times of solar maximum; they fall to middle and lower latitudes during the phase of decline, but again begin to seek higher latitudes at the minimum and period of increase.

2. The curve of limiting latitudes for greater disturbances reproduces very faithfully the form of the curve of total spotted area.

3. The process of decline is for spots to disappear first in the higher zones and then in the middle zones, while the lower zones may be affected equally at minimum and maximum.

4. There does not seem to be any indubitable evidence of an abrupt commencement of a new cycle by the appearance of spots in high latitudes.

5. The process of spot variation in latitude does not seem to

be due to the overlapping of cycles of activity, as demanded by Spörer's law.

6. Nor is it apparently due to the existence of a series of "spot-activity tracks," the subsidence of activity from maximum to minimum being zonal and the foci of activity in the zones occurring in different longitudes.

The Rotation Period of Saturn. *By* W. F. Denning.

The conspicuous spots visible on *Saturn* in 1903 offered an opportunity for accurately determining the rotation period of the planet which it was most desirable to utilise to the best possible advantage. I regretted, therefore, to see that Professor Hough had apparently misidentified certain of the markings, and deduced a rotation period in excess of the correct value (*Monthly Notices*, 1904 December).

Professor Hough places an exclusive reliance on the micrometric method of taking transits, and gives the times to tenths of a minute, but the number of the observations he employs are so limited that at least very grave doubts must exist as to his identifications. He regards all eye-estimated transits of markings on *Jupiter* and *Saturn* as useless, though Professor Barnard, Mr. Stanley Williams (*Monthly Notices*, 1904 March), and others have clearly shown that the latter are comparable with the former in regard to accuracy.

It is indeed quite fair to say that if all the micrometrically measured transits of *Jupiter's* spots were put on one side, and only the eye-estimated transits retained, our knowledge of Jovian phenomena would not suffer in the least!

The conclusions I arrived at respecting the identification and rotation period of the spots on *Saturn* (*Monthly Notices*, 1904 March) are, I believe, perfectly sound, and this is also the opinion of several well-qualified observers who have not only obtained transits, but have pretty thoroughly compared and investigated the details.

As I have previously stated, the identification of the individual objects is a point of greater importance than the method of taking transits; and to be certain of the correctness of the identifications a fair number of observations must be accumulated. The materials adduced by Professor Hough in his paper (*Monthly Notices*, 1903 December) are obviously too scanty for the individual spots to be followed with certainty. The spots were quite numerous, some of them pretty close together, and liable to variation in brightness, shape, and motion. Professor Hough relies upon an observation, after an interval of three weeks, of a "faint, difficult" spot on August 19 as being the same as Barnard's, though it was more than 5,000 miles nearer the